EVALUATION OF TRANSIENT BEHAVIOR OF GE:GA DETECTORS FOR ASTRO-F

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ABSTRACT

Two types of far-infrared detectors, the direct hybrid Ge:Ga array and the stressed Ge:Ga array, will be installed the next Japanese infrared astronomical satellite ASTRO-F. As a part of pre-launch calibration of the detectors, we investigated transient properties of single-element stressed and unstressed Ge:Ga detectors. We measured the transient response under wide ranges of signal and background photon influxes. To estimate the effects of cosmic-ray hitting, we also performed γ-ray irradiation of the detector by radioactive sources ^{60}Co and ^{137}Cs, and investigated differences in detector performance before and after the irradiation. At present, measurements of the transient effects in a flight model replica of the direct hybrid Ge:Ga array are underway. We summarize the experimentally observed transient characteristics in our detectors at various operating conditions, including the radiation effects.

INTRODUCTION

The Japanese infrared astronomical satellite, ASTRO-F, is scheduled for launch in early 2004. ASTRO-F carries two types of focal-plane instruments, one of which is the Far-Infrared Surveyor[1] (FIS). The FIS adopts a stressed Ge:Ga array of 5 x 15 and a normal monolithic arrays of 3 x 20 and 2 x 20 pixels to cover 50 to 200 μm in wavelength. FIS is designed primarily to perform an all-sky survey and additionally to have spectroscopic capability with a Fourier transform spectrometer.

All the photoconductors on-board the ISO satellite are affected by the transient peculiarities[2] and radiation-induced effects at various levels, and thus ground-based measurements prior to the launch are important for the proper treatment of the FIS observation data. Hence, we first investigated the overall transient behavior using a single-element stressed and unstressed Ge:Ga detectors under various photon influxes and γ-ray radiation environment. In order to further investigate transient properties peculiar to a detector array, we are also measuring the transient response of a flight-model replica of a Ge:Ga array.

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MEASUREMENTS OF SINGLE-ELEMENT DETECTOR

Measurement

We tested the Ge:Ga photoconductors with Ga concentration of 2×10^{14} cm^{-3} and a donor compensation ratio of less than 0.01. The element size is $1 \times 1 \times 1$ cm^3 for the stressed and $0.5 \times 0.5 \times 0.5$ cm^3 for the unstressed detector. The material is supplied by Sumitomo Metal Mining Company. A stress of up to 50 kg/mm^2 was applied to the Ge:Ga element with a compression mechanism using leaf springs and screws. The detector was operated at temperature of 1.6-1.9 K. In a nominal case, we applied a bias field of 0.3 V/cm for the stressed detector and 1.0 V/cm for the unstressed detector.

The measurement system consists of two blackbody sources and a cold chopper. We measured the slow response of the Ge:Ga detector against the step signal by driving the chopper in front of one of the blackbodies. The other blackbody works as a background source. We used a cryogenic stepping motor for the chopper, so that we could also measure AC responsivity of the Ge:Ga detector up to 80 Hz by the same system. By changing the temperatures of the two blackbodies (15 – 80 K) and numbers of attenuation filters in front of the detector housing, we changed the fluxes of signal and background photons independently. The readout circuit is a TIA (Trans-Impedance Amplifier) with a feedback resistance of 1 GΩ or 100 GΩ.

Slow transient response

Figure 1 shows examples of slow transient responses observed for the stressed and unstressed detectors under low photon fluxes. The upward and downward steps correspond to opening and closing the shutter, respectively. Slow transient response with a time constant of a few minutes cane be seen in the figure. As for the downward step, an amplitude fraction of the transient component to the total step is apparently small as compared with that for the upward step. We performed the measurement and the model fittings of the data for many conditions of photon fluxes. As a result, for the stressed detector, the two-component and one-component exponential models reproduced most of the upward and downward transient curves, respectively. The best-fit parameters of the transient model (time constants, amplitude fractions) were obtained by power-law functions of a photon influx[3]. The model also reproduced the most transient curves of the unstressed detector fairly well. One of the most notable feature is a hook response, which is clearly observed only under low photon fluxes. We did not observe a hook response for the stressed detector at all.

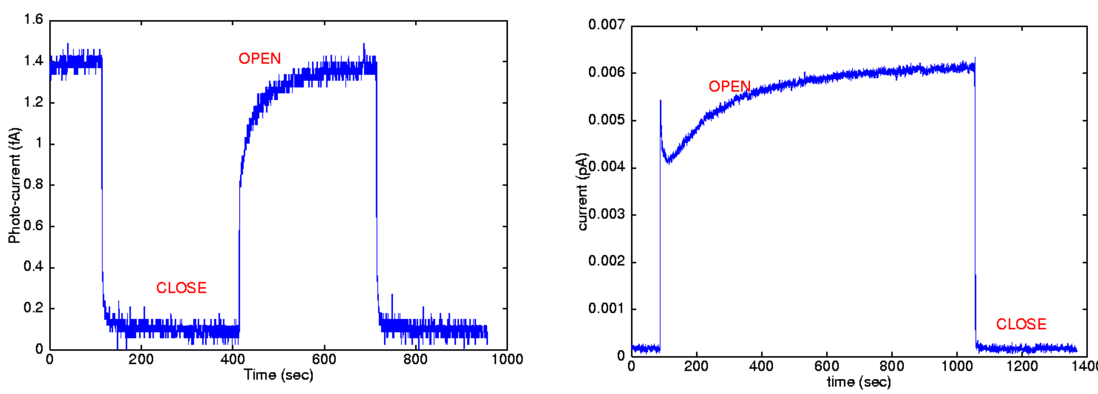

Figure 1: *Examples of the acquired transient data for the stressed detector (left panel) and the unstressed detector (right panel).*

Transient correction by our exponential model

In case of the ASTRO-F/FIS survey observation, signal changes are not stepwise, but rather gradual. However, it is difficult to derive continuously-changing reference signals in laboratory. Instead, by using a different chopper with a modified blade, we measured the detector response for multiple-step signals. An example of such measurement is shown in the left panel of Figure 2. The solid curve corresponds to the data obtained by clockwise rotation of the chopper, while the dotted curve is derived by counter-clockwise rotation. The difference between these curves is very large due to the transient response. The curves in the right panel are shown after corrections for the transient response by applying the above exponential transient model to the measured data. As seen in the figure, the difference between the curves is reduced considerably, which supports the applicability of our transient model to multiple-step signals.

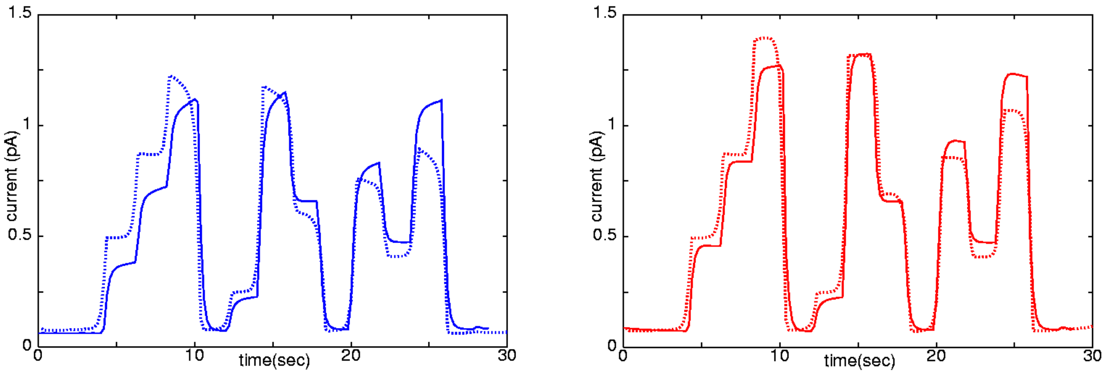

Figure 2: *(Left) Transient response for multiple-step changes of signals. The solid curve was derived by clockwise rotation of the chopper, while the dotted curve was derived by counter-clockwise rotation. (Right) The same data as in the left panel but shown after correction of transient responses by using the exponential transient model.*

Higher-frequency transient response

For the FIS Fourier spectroscopic observation, measurements of higher-frequency transient responses for modulated signals are important. We measured AC responsivity up to 80 Hz for various photon influxes. As a result, we found that the AC responsivity at frequencies higher than 30 Hz is reduced down to 20 % of the DC value under low photon influxes. The details will be reported elsewhere.

Radiation effects on response

We investigated radiation-induced effects under various photon influxes by irradiating the detector with radioactive sources. Two radiation sources, ^{60}Co with an activity 200 μCi and ^{137}Cs with 200 μCi , were used from outside the cryostat. For typical exposure, the absorbed dose was 0.05 rad. Typical behavior of the stressed detector before and after irradiation is presented in the left panel of Figure 3. It can be seen that even low-dose levels in our experiments dramatically change the response. In order to reduce the persistent enhancement in responsivity due to the residual effects of irradiation, we tested three kinds of curing methods: thermal annealing, exposure to infrared radiation, and high-voltage bias boosting. Our measurements showed that the annealing was the most effective among the three methods, and can restore the responsivity to the initial value with temperatures of 6 K for the stressed detector and 12 K for the unstressed detector.

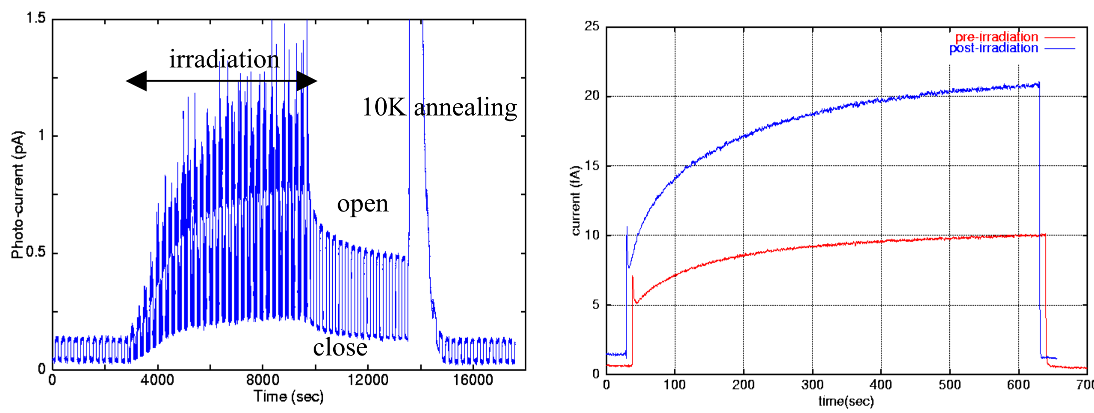

Figure 3: *(Left) Effects of γ-ray irradiation on the detector response. (Right) Changes of the slow transient response due to residual effects of γ-ray irradiation.*

The right panel of Figure 3 shows the upward transient curves of the unstressed detector before and after irradiation. It is found that the properties of the slow transient response change significanlty after irradiation; the time constant of the slow response decreases while the amplitude fraction increases. In other words, radiation-induced enhancement in AC responsivity is relatively small as compared with that in DC responsivity.

MEASUREMENTS OF ARRAY DETECTOR

Measurement of the transient response of the monolithic 20 x 3 Ge:Ga array which is flight-model replica is underway. Readout circuit is CTIA (Capacitive Trans-impedance Amplifier), composed of specially-made p-MOSFETs for low-temperature use, with a feedback resistance of 7 pF. The detector array is directly attached to the cold readout circuit through technique of indium bumping. The detectors are developed under collaborative research of the Communications Research Laboratory (CRE), Nagoya University, and the Institute of Space and Astronautical Science (ISAS). The Ge material itself is the same as that of the single-element detectors mentioned above. The semiconductor processing was performed by Hamamatsu Photonics K.K., and the p-MOS Ics were fabricated by NTT Electronics Technology Co..

We measured the response of the Ge:Ga photoconductor against the step irradiation by driving the cold shutter in front of the internal blackbody source. The detector was operated at temperature of 2.1 to 2.4 K and a bias field of 2.0 V/cm was applied in a nominal case. The transient features observed for the array are very similar to those derived by measurements of the unstressed single-element detector. One exception is that we have not observed the hook response as observed for the single-element detector. This could be explained by longitudinal configuration of electrodes adopted for the array detector rather than classical transverse configuration used for the single-element detectors[4].

We are also measuring non-stationary cross-talk which is one of the transient properties peculiar to array detectors by using a pin-hole mask just in front of the detector surface. So far, we have not observed serious transient behavior of pixels adjacent to an on-source pixel. The results on measurements of the array detector will be reported in a separate paper.

CONCLUSION

We investigated overall transient behaviors of stressed and unstressed one-element Ge:Ga detectors, which are slow responses for step changes of signals as well as higher-frequency responses for modulated signals. We achieved wide coverage of signal and background influxes. As for the slow response, the multi-component exponential model reproduces all the data fairly well, and behaviors for upward and downward steps are extremely different. From the measurements of the higher-frequency response, we found that the AC responsivity could be reduced down to 20 % of the DC responsivity. In order to investigate radiation-induced effects, we performed γ-ray irradiation from outside the cryostat in parallel with measurement of the slow response. We found that the γ-ray irradiation changes not only DC responsivity but also slow transient properties. At present, we are also measuring transient effects in a flight model replica of the direct hybrid Ge:Ga array. So far, the transient features observed for the array are very similar to those derived by measurements of the unstressed single-element detector, and we did not observe serious non-stationary cross-talk.

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